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Group Art Unit : 2711

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The attached documents are exact copies of the European patent application described on the following page, as originally filed.

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Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

97870170.4

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

N.A.S. Kettle

Blatt 2 der Bescheinigung
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Page 2 de l'attestation

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Demandeur(s):
INTERUNIVERSITAIR MICRO-ELEKTRONICA CENTRUM VZW
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Bezeichnung der Erfindung:
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Pixel structures, method of obtaining a calibrated read-out signal of a pixel structure

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PIXEL STRUCTURES, METHOD OF OBTAINING A CALIBRATED READ-OUT SIGNAL OF A PIXEL STRUCTURE

Field of the invention

The present invention is related to improving the image quality of the image in imaging devices.

A first object of the present invention is related to the pixel structure.

A further object of the present invention is related to the improvement of the image quality by a method of calibrating of a photosensitive element present in a pixel structure intended for imaging devices.

A further object of the present invention is related to the improvement of the image quality by a method of uniformisation of the image in an image device by cancellation of the appearance of column-shaped fixed pattern noise.

A further object of the present invention is related to the improvement of the image quality by a method of correcting isolated pixel values present in an image taken by imaging devices.

Technological background and problem definitions

Solid state image devices are well known. Virtually all solid-state imaging devices have as key element a photosensitive element being a photoreceptor, a photo diode, a photo transistor a CCD gate, or alike. Typically, the signal of such a photosensitive element is a current which is proportional to the amount of electromagnetic radiation (light) falling onto the photosensitive element.

A structure with a photosensitive element included in a circuit having accompanying electronics is called a pixel. Such pixel can be arranged in an array of pixels so as to build focal plane arrays or cameras systems.

Commonly solid state image devices are implemented in a CCD-technology or in a CMOS- or MOS-technology.

For the image sensors implemented in a CMOS- or MOS-technology, CMOS or MOS image sensors with passive pixels and CMOS or MOS image sensors with active pixels are distinguished. An active pixel is configured with means integrated in the pixel to amplify the charge that is collected on the light sensitive element. Passive pixels do not have said means and require a charge-sensitive amplifier that is not integrated in the pixel and is connected with a long line towards the pixel.

There is an ongoing effort to increase the performance of CMOS imagers such that a comparable image quality would be obtained as the one obtained with high end CCD imagers.

Due to the further miniaturisation of the CMOS electronics technology, it is possible to realise

complex CMOS- or MOS-based pixels as small as CCD-based pixels. It is a further advantage of CMOS- or MOS-based pixels that CMOS is a technology being offered by most foundries whereas CCD-technology is rarely offered and a more complex and expensive one.

A first problem in the CMOS based imaging devices appears because material imperfections and technology variations have as effect that there is a non-uniformity in the response of the pixels in the array. This effect is caused by a non-uniformity or fixed pattern noise (FPN) or by a photoresponse non-uniformity (PRNU). Correction of the non-uniformity needs some type of calibration, e.g. by multiplying or adding/subtracting the pixel's signals with a correction amount that is pixel-dependent.

A method to obtain this correction factor is to illuminate the array with a homogenous light flux, and to use the resulting signals in a calibration procedure. Executing such procedure during the operation of an imaging device is of course very awkward, and is not possible in many cases.

Several methods to cancel FPN furthermore are based on techniques that are often called correlated double sampling or offset compensation. The methods in general are based on the following: the signal of the pixel is subtracted from the signal of the same pixels in a reference state (this reference state is typically the reset or dark state). The difference of both signal is free of pixel-related non-uniformity. However, if the differencing circuit is common for a part of the imager (typically, common for one column), a new non-uniformity will originate due to the non-uniformity of the

differencing circuits. In a typical APS imager with common column buffers or column amplifiers, the new fixed pattern noise is column dependent, and is visible in the image as a shade of vertical stripes.

A stripe-shaped FPN is much more annoying than a pure statistical FPN. It is seen in experiments that a true random FPN of 5% RMS is barely visible to the human eye, whereas a stripe-shaped FPN remains visible even when the amplitude is below 1% RMS. The reason is that the human eye has a kind of built-in spatial filter that recognises larger structures even when they have low contrast.

Even if in the case that we have no fixed pattern noise, the photoresponse non-uniformity can be different from 0.

Another problem arises due to processing imperfections, statistics, etc. This means that typically, a finite number of pixels in a sensor array will be defective (hard faults) or yield a signal that deviates visibly from the "exact" pixel value. Such faults appear as white or black (or grey) points in the image. This class of faults in the sequel is called an isolated pixel value.

A known way to cancel these spots is to store a list of them and of their positions in the image in a memory. In an image processing step, the isolated pixel value is then replaced by e.g. the average of the surrounding pixels. This method is viable, but has the disadvantage that it requires a memory. Moreover, it cannot handle isolated pixel values that appear intermittently or only in certain cases. A good example, is a so-called dark current pixel. Such pixels will appear

white in a dark environment, but will behave normal in a bright environment.

Other ways to cancel isolated pixels faults have been proposed, e.g. the spatial median filter or other types of Kalman filters can be used to remove such isolated faults. Unfortunately, such filters do also remove useful detail from the image. Consider the image of a star covered sky with an image sensor that has some faulty pixels that appear white. The quoted filters are not able to remove the white point due to faults, and leave the white points that are stars untouched.

Aims of the invention

The present invention aims to suggest a pixel structure and methods to improve the image quality, more in particular the image non-uniformity of in array of pixels.

Main characteristics of the present invention

As a first object, the present invention is related to a pixel structure comprising in a parallel circuit configuration a radiation sensitive element and an adjustable current source. In said pixel, the current source is adapted for delivering a current that is higher than or as high as the current being generated by radiation, preferably light, impinging on said radiation sensitive element.

As a second object, the present invention is also related to a method of obtaining a calibrated read-out signal of a pixel structure having at least a radiation sensitive element, the method comprising the steps of:

- while forcing a current generated by said current source on said photosensitive element, reading-out said pixel structure to thereby obtain a first signal;

- reading-out said pixel structure with said current source off to thereby obtain a second signal;

- subtracting said first signal from said second signal, the resulting signal being amplified to obtain said read-out signal.

A method is suggested of calibrating a photosensitive element such as a photoreceptor or a photodiode in a pixel having a structure which comprises at least a photosensitive element, a load transistor in series with the photosensitive element and means comprising at least another transistor coupled to said photosensitive element and said load transistor for reading out the signal acquired in said photosensitive element and converted to a voltage drop across to said load transistor.

The method is characterised by the fact that a current source is connected in parallel possibly with a series switch to the photosensitive element, said current source being on in a condition very similar to the condition of an illumination of the pixel with a high light intensity thereby performing a calibration for instance of the FPN or PRNU of the pixel.

As a further aspect, the present invention is also related to an image sensor comprising an array of pixels, the pixel of one column of the array being connected to a common output circuit having at least two amplifying elements, the output circuits of the column of the array being connected to a common output amplifier with at least two input terminals, the sensor further comprising means for switching the output signals of the amplifying

elements to respectively first and second input terminals of said common output amplifier for essentially each consecutive row of said arrays.

As a further object, the present invention is related to a method of reading-out an array of pixels, the pixel of one column of the array being connected to a common output circuit having at least two amplifying elements, the output circuit of the columns of the array being connected to a common output amplifier with at least two input terminals, the method comprising the steps of:

- amplifying the output signals of essentially each pixel of one column in the first amplifying element thereby obtaining a set of amplified pixel output signals,
- amplifying the reference signals of essentially each pixel of one column in the second amplifying element, thereby obtaining a set of amplified pixel reference signals,
- consecutively, for essentially each pixel of said column imposing the amplified pixel output signal to a first or a second terminal of said common output amplifier and imposing the amplified pixel reference signal to a second or a first terminal of said common output amplifier, while switching the amplified pixel output signal to respectively said first and said second terminals for essentially each consecutive pixel of said column, said reference signal being imposed to the other terminal of said common output amplifier.

As another aspect, the present invention is related to a method of cancelling the appearance of column-shaped FPN or PRNU wherein crossbar switches are placed on two adjacent columns.

As a further object, the present invention is related to a method of replacing an isolated pixel value in the image of an image sensor, being an array of pixels, the method comprising the step of:

- limiting said isolated pixel value between or to an upper and/or a lower bound that is derived from the values of pixels in the immediate neighbourhood of the said isolated pixel value.

Brief descriptions of the drawings

Figure 1 represents an embodiment of a pixel according to a first aspect of the present invention and permitting a calibration of the photosensitive element present in the pixel structure.

Figure 2 represents a graph of a logarithmic pixel output voltage versus the light intensity when using the method of calibration of the photosensitive element according to the present invention.

Figure 3a represents another embodiment of the pixel according to the first aspect of the present invention where the calibration current is given by the discharge of a capacitor.

Figure 3b represents a graph of the pixel current versus time the when performing the method of calibration of the photosensitive element according to a specific embodiment of the present invention and using the pixel structure of figure 3a.

Figure 4a represents a particular implementation of a column FPN cancellation method and the

corresponding image sensor structure.

Figure 4b represents an embodiment of a cross-bar switch.

Figure 5 represents a method of correcting isolated white pixel values being present in an image composed by an array of pixels.

Brief descriptions of preferred embodiments of the present invention

Figure 1 is representing a pixel (10) where the photosensitive element consists of a photoreceptor (1) which yields a current proportional to the light intensity. Such a photosensitive element can also be a photodiode, a photo BJT, a photogate, or a CCD-cell. The reading of such pixels for a certain light intensity is in fact the reading of as moderate photo current or charge of the photoreceptor. Such pixel when forming an array often exhibit a relatively large non-uniformity over the arrays. This non-uniformity is typically an offset in the output voltage, as shown in figure 2 for a logarithmic response pixel. The transfer curves for each pixel do not coincide.

Figure 2 represents the output voltage versus the input flux for a set of logarithmic pixels. The curves are parallel, but have an offset relative to each other. The offset can be determined by imposing a high current on the photoreceptor (1). The signal obtained for each pixel in this way must be subtracted from the "normal" reading of the pixel.

In order to calibrate the pixel non-uniformities, and to be able to restore the precise value of the photo current, a second reading of the same pixel is done with a known current. By equivalence, the photo

current is replaced with a current that originates from a current source (2). This is an advantageous method as it does not involve illumination of the device.

The said current source (2) can of any kind that is known to the man skilled in the art. Of course, it is advantageous that this current source is small in size and precise. Possible implementations are:

- a fixed current source, outside the pixel, and common for part of the imaging array. The source can be connected to several pixels in turn by switches.
- a MOSFET transistor connected as current source, to be placed inside each pixel. The current source can be turned on by applying a certain DC voltage between source and gate. The current source can be turned off by turning of the gate voltage.
- the current source may be composed of a "switched capacitor" circuit (see figure 3), where the current source is not stable, but composed of the discharge of at least one capacitor (33). In the simplest implementation, the current source in the figure is a capacitor (33) that is just discharged on the photo detector node, which yields indeed a high current during a short time. But this can be sufficient for the purpose.

Figure 3 is a schematic view of the implementation of the current source as a switched capacitor network. The current is a transient of a discharge of the discharge of the capacitor onto the photo diode node "V". Two samples are taken from the diode node voltage: A1, being the normal signal, and A2 taken during or after the transient of the discharge. The signal level of A2 depends only on the height of the discharge current,

and not on the photo current which is smaller. The difference (Δ) between A1 and A2 is then a measure of the normal sign level which is free of offset or of PRNU.

According to a second aspect of the present invention, a method of cancellation the appearance of the column-shaped FPN is suggested.

Generally, in an array of pixels, all pixels of one column are passed through the same channel: within the column there is thus no FPN or PRNU, only from column to column. In other words, columns have a statistically spread offset referred each to other. The present invention will modulate the offset within each column, so that the average offset of a column becomes zero. On the average, columns will have no more offset referred to each other and stripe-shaped FPN will disappear. Instead, there will be a high-frequency (spatial high frequency) FPN inside each column, as stated above, the human eye is much less sensitive to high spatial frequencies, these might be invisible to the eye when less than 5% of the signal amplitude.

In the figure 4, a column of an APS image sensor can be recognised. (40), (50) and (60) are three pixels of a column of an image sensor. The pixel's signal on the column bus "K" is fed to the optional buffer amplifier A1, and/or stored on capacitor C, and fed to amplifier A2. By the relative timing of the addressed pixel's reset pulse and the control of the switch S3, one can make that the pixel's signal and its reference level are available on amplifiers A1, reps. A2. The fact that the signal passes through the column amplifiers A1 and A2, is a source of offset non-uniformity, which is column related and causes a vertical stripe-shaped FPN. More

specifically, each column will feature an average "OV" offset voltage referred to the average of the other columns.

Switches (41) and (42) are crossbar switches. Suppose that they are in the forward direction either in crossed directions. In both cases, the signal on the capacitor C goes to the input of the output amplifier, and the signal on K goes to the + input of the output amplifier. Yet, the "OV" of the column will be positive in the one case and negative in the other case. Of the switches (41)/(42) are modulated, e.g. turned direction at each new row of the image, then the average offset of a column will be zero. For each individual pixel of a column, there will be indeed remain an offset which is + or - OV but this is a very small feature, and is not recognised by the eye as a stripe.

According to a third aspect, the present invention is able to discriminate between isolated pixel faults and features in the real image. In the case of an image of a star covered sky, it should be noted that the fact that the image projected through a lens is never perfectly sharp. Even with good lenses, a star image is not projected on a single pixel. Always the point like source of the start will be smeared out over a central pixel and a few neighbours. In a 1-dimensional cross section, a star image will look like the image in Fig. 5A, while an isolated pixel fault will look like in fig. 5B.

In the above simple example, the peak in fig. 5B should be removed, while the peak in 5A should remain untouched.

The advantage is clear, only device faults are corrected while normal images are left untouched. The

operation causes no visible image degradation in faultless parts of the image.

According to this third aspect of the present invention, a method to remove an isolated whiter or darker pixel from the image is suggested. This method consists in limiting the value of every individual pixel between an upper and/or a lower bound that is/are derived from the values of pixels in the intermediate neighbourhood of the said pixel.

Preferably, the upper and/or lower bounds are found by extrapolation of the neighbourhood pixel values towards the position of the said individual pixel. The upper and/or lower bound are/is a combination of one or several such 1-D or 2-D extrapolations done with different methods, and/or from different sides of the said individual pixel.

Preferably, extrapolation is the linear extrapolation of a neighbour (N1) of the said individual pixel (IP) and the neighbour thereafter (N2). The extrapolated value is calculated as 2*N1-N2 or more general: N1 + n* (N1-N2) where the parameter n is a real number, typically between 0 and 3.

According to another preferred embodiment, the calculation of the upper bounds is performed by extrapolating values from the two sides of said individual pixels. The advantage is that only the pixels data in 1 line of an image are required, which saves memory and operations and allows straightforward implementation as a pipelined filter. Also such a filter is able to correct a vertical line defect.

In the example of figure 5A and 5B, five pixels in a neighbourhood (a 5-pixel "kernel") are taken.

The experience is that smaller kernels do not yield good results. Larger kernels may give some improvements compared to the 5-pixel kernel.

CLAIMS

1. A pixel structure (10) comprising in a parallel circuit configuration a radiation sensitive element (1) and an adjustable current source (2).

2. A pixel structure as recited in claim 1, wherein said current source (12) is adapted for delivering a current that is higher than or as high as the currents being generated by radiation impinging on said radiation sensitive element.

3. A pixel structure as recited in claim 2, wherein said radiation is electromagnetic radiation such as light.

4. A pixel structure as recited in any one of the preceding claims, wherein said current source (2) is a transistor.

5. A pixel structure (30) as recited in any one of the preceding claims, wherein said current source is a switched capacitor circuit, said circuit comprising a capacitor (33), and a switch (35) connected to the capacitor (33).

6. A pixel structure (30) as recited in claim 5, further comprising a further switch (34) in-between said capacitor and said radiation sensitive element (31), and the second switch (35) being preferably in a parallel configuration with said capacitor (33).

7. A pixel structure as recited in any one of the preceding claims, further comprising a load transistor in series with the photosensitive element (1) and means (7) comprising at least another transistor (8) coupled to said photosensitive element (1) and said load transistor (7) for

reading out the signal acquired in said photosensitive element and converted to a voltage drop across said load transistor, and further comprising a switch (9) in-between said current source (12) and said photosensitive element (1).

8. A method of obtaining a calibrated read-out signal of a pixel structure having at least a photosensitive element and a current source, the method comprising the steps of:

- while forcing a current generated by said current source on said photosensitive element, reading-out said pixel structure to thereby obtain a first signal;
- reading-out said pixel structure with said current source off to thereby obtain a second signal;
- subtracting said first signal from said second signal, the resulting signal being amplified to obtain said read-out signal.

9. A method as recited in claim 8, wherein said pixel is a CMOS based pixel structure having a load transistor in series with said photosensitive element.

10. An image sensor comprising an array of pixels (40,50,60), the sensor including at least one current source (S3,C) being connected to the pixel, the pixel of one column of the array being connected to a common output circuit (44) having at least two amplifying elements (A1, A2), the output circuits of the column of the array being connected to a common output (43) amplifier with at least two input terminals, the sensor further comprising means (41,42) for switching the output signals of the amplifying elements to respectively first and second input terminals of said common output amplifier (43) for essentially each consecutive row of said arrays.

11. An image sensor as recited in claim 10, wherein said means comprises at least two cross-bar switches (41,42).

12. A method of reading out an array of pixels, wherein at least one current source being connected to the pixel, the pixel of one column of the array being connected to a common output circuit having at least two amplifying elements, the output circuit of the columns of the array being connected to a common output amplifier with at least two input terminals, the method comprising the steps of:

- amplifying the output signals of essentially each pixel of one column in the first amplifying element thereby obtaining a set of amplified pixel output signals,

- amplifying the reference signals of essentially each pixel of one column in the second amplifying element, thereby obtaining a set of amplified pixel reference signals,

- consecutively, for essentially each pixel of said column imposing the amplified pixel output signal to a first or a second terminal of said common output amplifier and imposing the amplified pixel reference signal to a second or a first terminal of said common output amplifier, while switching the amplified pixel output signal to respectively said first and said second terminals for essentially each consecutive pixel of said column, said reference signal being imposed to the other terminal of said common output amplifier.

13. A method of replacing an isolated pixel value in the image of an image sensor, being an array of pixels, and wherein at least one current source is

connected to the pixels, the method comprising the step of:

- limiting said isolated pixel value between or to an upper and/or a lower bound that is derived from the values of pixels in the immediate neighbourhood of the said isolated pixel value.

14. A method as recited in claim 13, wherein said upper and/or lower bounds are found by extrapolating the immediate neighbourhood pixel values towards a value that corresponds to the position of said individual pixel in relation to the immediate neighbourhood pixels.

15. A method as recited in claim 14, wherein said upper and/or lower bounds are found by extrapolating the values of a neighbour (V_1N) of the pixel having said isolated pixel value and of the neighbour thereafter (V_2N), the replacing pixel value being calculated as $V_1N+n*(V_1N-V_2N)$, n being a real number.

16. A method as recited in claim 15, wherein said neighbour and the neighbour thereafter are on the same row of said array.

17. A method as recited in claim 13, wherein said upper bound is the maximum of a set of values, said set being determined as the pixel values (a,b,c,d,e) of pixels on the same row of said array as said isolated pixel, said upper bound being calculated as

cmax = F(a,b,c,d), or cmax G(E(a,b), E(e,d), E(b), E(d))

where F is a non-linear or linear function,

G is a non-linear GE or linear function, E is an extrapolating function

18. A method as recited in claim 17, wherein

cmax= MAX(2b-a,2d-e,b,d)

together with

$$cmin = MIN(2b-a, 2d-e, b, d)$$

with MAX () yielding the maximum, respectively the minimum of the arguments, the corrected c-value being obtained as

$$c = MIN(MAX(c, cmin), cmax)$$

5

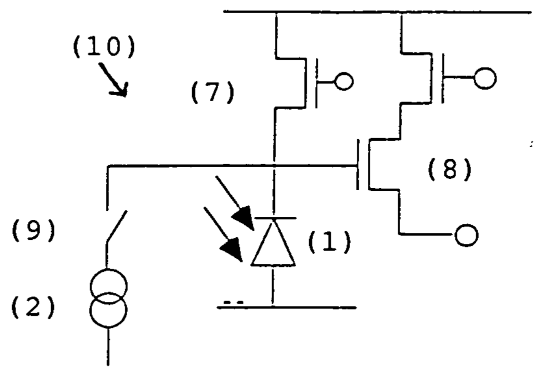
(10)
(7)
(8)
(9)
(1)
(2)

FIG.1

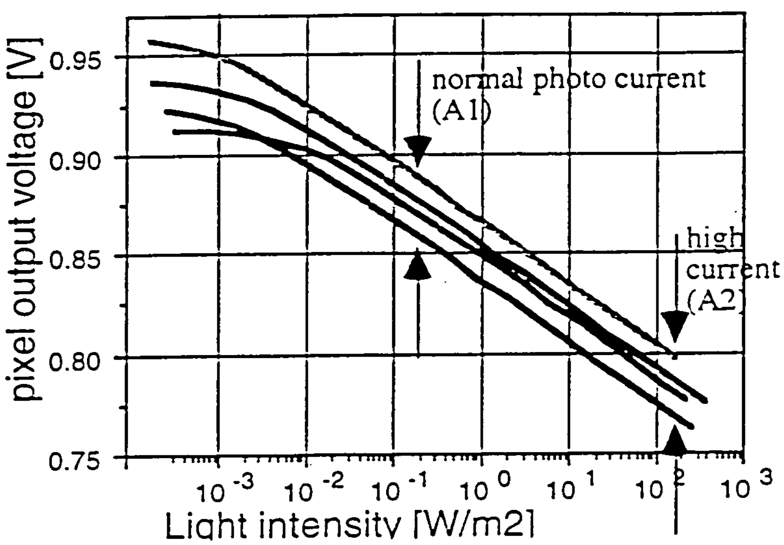
pixel output voltage [V]
0.95
0.90
0.85
0.80
0.75
normal photo current (A1)
high current (A2)
10 -3
10 -2
10 -1
10 0
10 1
10 2
10 3
Light intensity [W/m2]

FIG.2

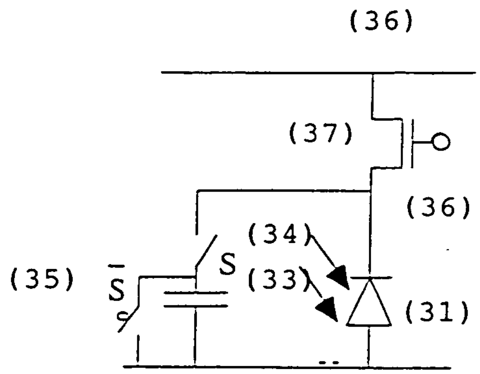

FIG. 3a

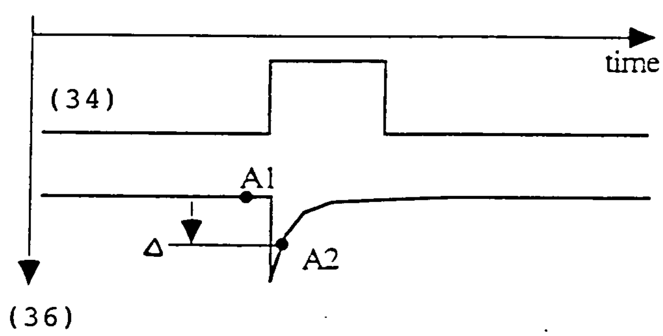

FIG. 3b

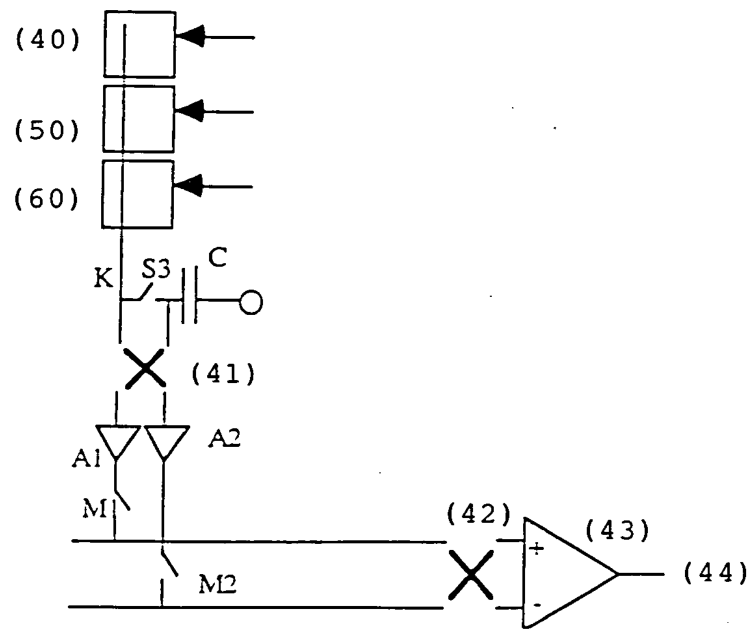

FIG. 4a

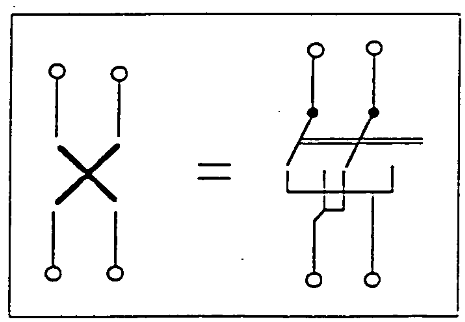

FIG. 4b

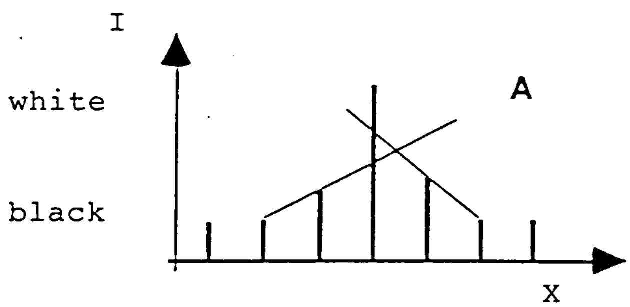

FIG. 5a

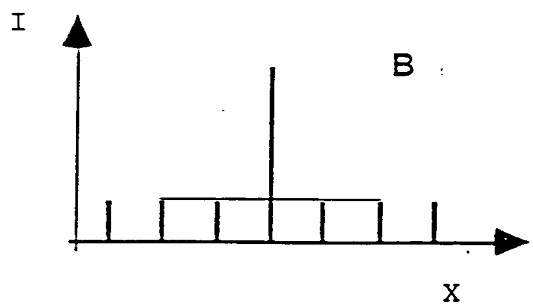

FIG. 5b

ABSTRACT

PIXEL STRUCTURES, METHOD OF OBTAINING A CALIBRATED READ-OUT SIGNAL OF A PIXEL STRUCTURE

A pixel structure (10) comprising in a parallel circuit configuration a radiation sensitive element (1) and an adjustable current source (2).

Said current source (12) being adapted for delivering a current that is higher than currents being generated by electromagnetic radiation impinging on said photosensitive element.

An image sensor comprising an array of pixels (40,50,60), the sensor including at least one current source (S3,C) being connected to the pixel, the pixel of one column of the array being connected to a common output circuit (44) having at least two amplifying elements (A1, A2), the output circuits of the column of the array being connected to a common output (43) amplifier with at least two input terminals, the sensor further comprising means (41,42) for switching the output signals of the amplifying elements to respectively first and second input terminals of said common output amplifier (43) for essentially each consecutive row of said arrays.